

CHARACTERIZATION OF PULTRUDED FIBER REINFORCED HIGH PERFORMANCE POLYMER MATRIX COMPOSITE WITH CARBON NANO TUBES

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ABSTRACT

Polymer matrix composites (PMC) have established themselves as engineering structural materials, not just as laboratory curiosities or cheap stuff for making chairs and tables. Glass fiber reinforced polymers represent the largest class of PMC. Introducing carbon Nanotubes (CNT) into matrix material enhances the mechanical properties of the composite materials. pultrusion process suites our requirements when compare to other processes. Material such as glass fibers with epoxy resin and cynate ester are used in this process because of their light weight and good mechanical properties. To improve the strength and conductivity of the polymer composite, CNT is used. In the present work, pultrusion of 3 mm diameter wire is carried out for glass fiber with epoxy and cynate ester respectively. So volume fraction test is conducted using crucible furnace. CNT is introduced in two different compositions to verify the rate of increase of the mechanical strength and glass transition temperature. To avoid agglomeration of CNT, ultrasonicator is used for proper mixing. Tensile test is carried out using dynamic testing machine and glass transition temperature (T_g) is carried out by using differential scanning calorimeter (DSC) test results indicate that increase in percentage of CNT shows increase in tensile strength of glass fiber reinforced polymer(GFRP).

KEYWORDS: Glass Fibers, Epoxy Resin, Pultrusion Process, Cynate Ester

INTRODUCTION

Composites are one of the most advanced and adaptable engineering materials known to men. Progresses in the field of materials science and technology have given birth to these fascinating and wonderful materials. Composites are heterogeneous in nature, created by the assembly of two or more components with fillers or reinforcing fibers and a compactable matrix. The matrix may be metallic, ceramic or polymeric in origin. It gives the composites their shape, surface appearance, environmental tolerance and overall durability while the fibrous reinforcement carries most of the structural loads thus giving macroscopic stiffness and strength.

Pultrusion [1] is a composite fabrication process designed for structural shapes. The investment cost is very high and therefore only feasible for mass production parts. Fibers are drawn through a resin bath and then through a forming block. Heaters are used to insure fast curing through steel dies and then the part is cut to proper length. Pultruded parts are strongest in the longitudinal direction because of their fiber orientation. Fiber orientation can be changed to increase strength in other directions. Solid, open sided and hollow shapes can be produced at almost any length. Cores such as foam and wood can be built inside of the pultruded shapes. Due to the pressure and designs of production, protruded production can be up to 95% effective in material utilization.

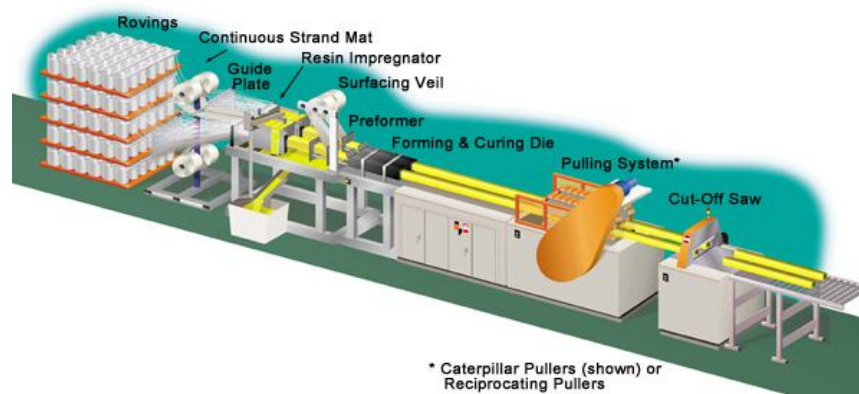


Figure 1: Pultrusion Process

GLASS FIBERS

Glass fibers (GF) are the most common reinforcement for polymeric matrix composites. Their principal advantages are the relationship between their low cost, high tensile strength, high chemical resistance, and insulating properties. The disadvantages are low tensile modulus, relatively high specific gravity, sensitivity to abrasion during handling, low fatigue resistance, and high hardness.

E-glass and S-glass are the types of fibers more commonly used in the fiber-reinforced plastic industry-glass fibers have the lowest cost of all commercially available reinforcing GFs, which is the reason for their widespread use in the fiber-reinforced plastic industry.

Table 1: Properties of Glass Fiber as per the Manufacturer

Fiber Type	Tensile Strength (MPa)	Young's Modulus (GPa)	Density (Kg/m ³)	Co-eff. of Thermal Exp. (K ⁻¹)
E-glass	1250	70	2550	4.7X 10 ⁻⁶



Figure 2: Glass Fiber Reinforcement of having 1200 Tex

EPOXY RESIN

Epoxy resin has been used in a wide range of fields, such as paints, electricity, civil engineering, and bonds. This is because epoxy resin has excellent bonding property, and also after curing, it has excellent properties on mechanical strength, chemical resistance, and electrical insulation [2]. In addition, epoxy resin is able to have various different properties as it is combined and cured together with various curing agents. This issue describes the types of curing agents for epoxy resin and characteristics comparing to Three Bond products. The epoxy resin compositions of three bond currently on the market are the three bond 2000 series (base agent for epoxy resin), the three bond 2100 series (curing agent for epoxy resin), and the three bond 2200 series (one-part thermal cure epoxy compound resins).

Table 2: Properties of Epoxy Resin Given by Manufacturer

Test	Result Unit	Requirement	Result
Colour on gardener scale	GS	0 to 1	0.08
Epoxy value	Eq/kg	5.25 to 5.4	5.38
viscosity@25 ⁰ c	MPas	1000 to 12000	11250
Martens value	⁰ C	145 to 175	152



Figure 3: Epoxy Resin with Suitable Hardener

CYNATE ESTER

Traditional epoxy resin systems have long been used for vacuum impregnation of large electro-magnets. However, the mechanical strength of these systems is disappointingly low when operated at temperatures above about 70°C where the failure mechanism is more often by adhesion at the copper interface than by cohesion within the resin. A range of resin systems based on cyanate ester are currently being developed by CTD Inc. which are suitable for vacuum impregnation[3] and may offer advantages over the epoxy resin systems.

Table 4: Properties of Cynate Ester Given by the Supplier

Resin	Density	Tensile Properties			DMA (Tg) °C
		Ultimate Strength (MPa)	Young's Modulus (GPa)	Percentage Elongation	
RS-14	1.200	80	2.8	5.1	253



Figure 4: Cynate Ester

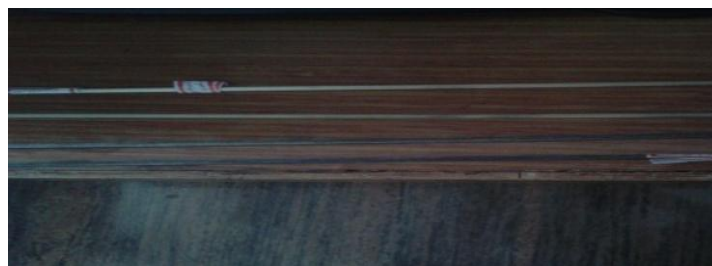


Figure 5: GFRP Samples are Produced by Using Pultrusion Machine

VOLUME FRACTION

Volume fraction of the pultruded composite wire [4, 5] is determined by using crucible furnace and the procedure for glass fiber with epoxy resin is as follows

- A crucible is heated to 600°C for 10 min or more. It was then cooled to room temperature and its mass was determined to the nearest 1.0 mg. This was recorded in the data sheet.
- The laboratory exhaust fan or ventilation system was turned on.
- The mass of the specimen and the crucible together was determined to the nearest 1.0 mg.
- The crucible and the specimen were placed in the furnace. The heating element was turned on to 565°C . The specimen is allowed to remain in the furnace for a minimum of one hour or until the entire matrix has disappeared (extra time is required for thicker laminates).
- The crucible and the remains were removed from the furnace and cooled to room temperature. Then they were carefully placed on a gram scale and the post burn-out mass was determined.
- The same procedure is carried for glass fiber with cynate ester resin but the temperature of the heating element should be 700°C

TENSILE TEST

The tensile test of the prepared samples is conducted by dynamic tensile testing machine as shown in Figure 6.



Figure 6: Dynamic Tensile Testing Machine

GLASS TRANSITION TEMPERATURE (T_g)

The glass transition temperature (T_g) is one of the most important properties of any epoxy and is the temperature region where the polymer transitions from a hard, glassy material to a soft, rubbery material [6-8]. As epoxies are thermosetting materials and chemically cross-link during the curing process, the final cured epoxy material does not melt or reflow when heated (unlike thermoplastic materials), but undergoes a slight softening (phase change) at elevated temperatures.

The glass transition temperature, not to be confused with melting point (T_m), is the temperature range where a thermosetting polymer changes from a hard, rigid or “glassy” state to a more pliable, compliant or “rubbery” state.

In actuality T_g is not a discrete thermodynamic transition, but a temperature range over which the mobility of the polymer chains increase significantly.



Figure 7: Differential Scanning Calorimetry (DSC)

RESULTS AND DISCUSSIONS

The results from the crucible furnace for glass fiber with epoxy resin and cynate ester resin are as follows

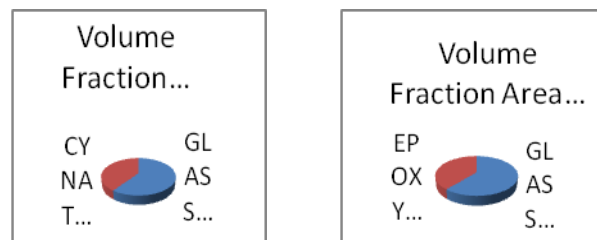


Figure 8: Volume Fraction of GFRF with Epoxy Resin and Cynate Ester Resin

THE THEORETICAL STRESS FOR GFRP SAMPLES WITH EPOXY

Theoretical stress can be calculated by using formula

$$\sigma = \sigma_f * f_f + \sigma_m (1 - f_f)$$

σ_f = tensile strength of fiber

σ_m = tensile strength of matrix

Table 5: Theoretical Stress for GFRP Samples with Epoxy Resin

Specimen Description	Diameter(mm)	Tensile Strength (MPa)
GFRP without CNT	2.96	780
GFRP with 0.5% CNT	2.96	1056
GFRP with 0.75% CNT	2.96	1194

Table 6: Theoretical Stress for GFRP Samples with Cynate Ester

Specimen Description	Diameter(mm)	Tensile Strength N/mm ²
GFRP without CNT	2.96	782

TENSILE TEST RESULTS

Table 7: Tensile Test Results

Specimen Description	Diameter (Mm)	Tensile Strength (Mpa)
GFRP without CNT	2.96	529
GFRP with 0.5% CNT	2.96	659
GFRP with 0.75% CNT	2.96	964

Table 8: Tensile Test Results Obtained from the Dynamic Testing Machine for GFRP Samples with Cynate Ester

Specimen Description	Diameter(mm)	Tensile Strength (Mpa)
GFRP without CNT	2.96	430

GLASS TRANSITION TEMPERATURE (T_g) OF GFRP SAMPLES

Glass transition temperature of the GFRP sample with epoxy resin is as follows

On set peak temperature = 174.93 °C

Peak temperature = 177.31 °C

End set peak temperature = 180.33 °C

The peak temperature is the glass transition temperature of the GFRP sample with epoxy resin which is equal to 177.31 °C

The glass transition temperature of the GFRP samples with cynate ester resin is as follows

On set peak temperature = 208.35 °C

Peak temperature = 220.36 °C

End set peak temperature = 223.60 °C

The peak temperature is the glass transition temperature of the GFRP sample with cynate ester resin which is equal to 220.36 °C.

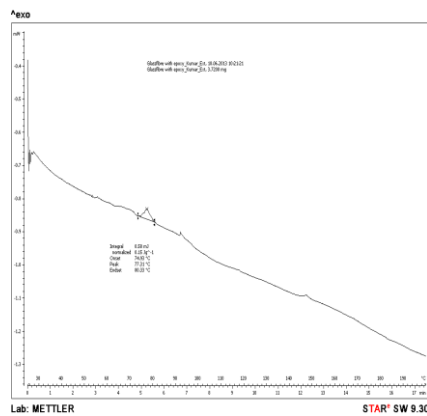


Figure 9: The Glass Transition Temperature of the GFRP Samples with Epoxy Resin

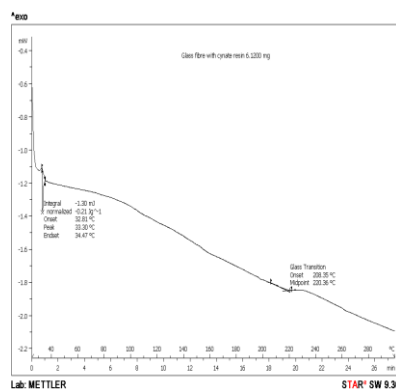


Figure 10: The Glass Transition Temperature of the GFRP Samples with Cynate Ester Resin

COMPARISON OF RESULTS

Increase in tensile strength of the GFRP samples with epoxy resin and cynate ester resin while percentage of CNT increases.

Sample 1= GFRP without CNT

Sample 2=GFRP with 0.5% CNT

Sample 3=GFRP with 0.75% CNT

As the percentage of CNT increases tensile strength also increases in the Pultruded samples.

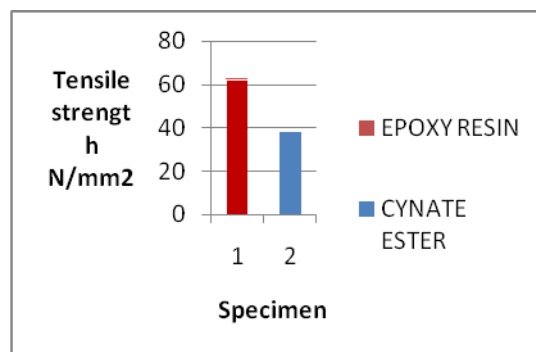


Figure 11: Comparison of Tensile Strength of the GFRP Samples with Epoxy Resin

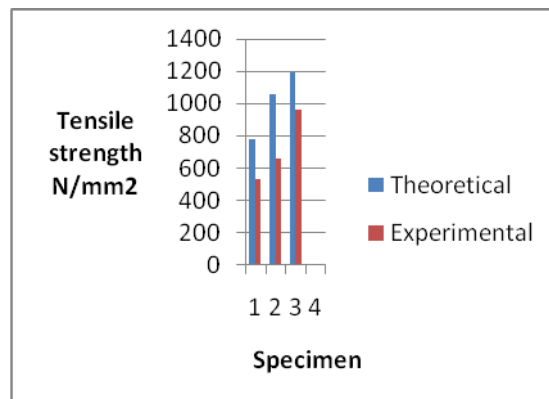


Figure 12: Comparison of Experimental and Theoretical Result of Tensile Strength for GFRP Sample with Epoxy Resin

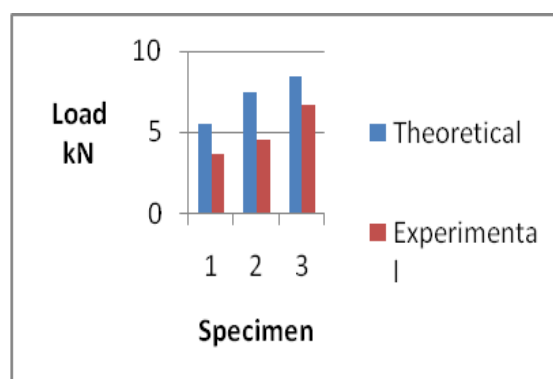


Figure 13: Comparison of Experimental and Theoretical Result Load for GFRP Sample with Epoxy Resin

CONCLUSIONS

- Polymer composites wires were Pultruded by glass fibres. here epoxy and cynate ester resin used as a matrix

material. Multi-walled carbon Nano tubes were introduced in two composition to the matrix material and then Pultruded again based on mechanical test conducted, following conclusions are made.

- Tensile strength of the GFRP samples with 0.5% CNT IS 16% more than the GFRP without CNT. And GFRP with 0.75% have tensile strength 25% more than GFRP without CNT and GFRP with 0.75% CNT have tensile strength 9% more than the GFRP with 0.5% CNT.
- Tensile strength of the GFRP sample with epoxy resin is 18.7% more than the GFRP sample with cynate ester resins both without CNT.
- Glass transition temperature (T_g) of GFRP sample with cynate ester resin is too higher than the Glass transition temperature (T_g) of GFRP samples with epoxy resin. so the cynate ester resin have more thermal conductivity than epoxy resin.

REFERENCES

1. Mel M. Schwartz, *Composite Materials: Processing, Fabrication and Applications*, Journal of Minerals & Materials Characterization & Engineering Vol. 2, 1997, pp119-176
2. S.M.Moschiar, M.M.Reboredo, A. VazquezI, *Pultrusion Process*, Institute of Materials Science and Technology (INTEMA) , 1991, pp16-32.
3. Francesca Nanni, Giovanni Ruscito, Debora Puglia, Andrea Terenzi, J.M. Kenny, Gualtiero Gusmano, *Effect Of Carbon Black Nanoparticle Intrinsic Properties On The Self – Monitoring Performance Of Glass Fiber Reinforced Composite Rod*, Composite Science And Technology, 2011, pp1-8.
4. F.G. Silva, F.Ferreira, C. Costa, M.C.S. Ribeiro, and A.C. Meira Castro, *Comparative Study About Heating Systems for Pultrusion Process Composites*, ARPN Journal of Engineering and Applied Sciences, 2012, pp1823–1829.
5. Christopher S. Grimmer, C.K.H. Dharan, *Enhancement of Delamination Fatigue Resistance in Carbon Nanotube Reinforced Glass Fiber/Polymer Composites*, Composites Science and Technology, 2010, pp901–908.
6. Naveed A. Siddiqui , Erin, Li.Man-Lung Sham , Ben Zhong Tang , Shang Lin Gao , Edith Mäder , Jang-Kyo Kim, *Tensile Strength of Glass Fibers with Carbon Nanotube–Epoxy Nano Composite Coating: Effects of CNT, Morphology And Dispersion State Composites: Part A* 41, 2010, pp539–548.
7. Thomas Keller, Tommaso Tirelli, Aixi Zhou, *Tensile Fatigue Performance of Pultruded Glass Fiber Reinforced Polymer Profiles Composite Structures*, International Journal of Current Engineering and Technology, 2005, pp 235–245.
8. Emrah Bozkurt, Kaya, Metin Tanog, *Mechanical and Thermal Behavior of Non-Crimp Glass Fiber Reinforced Layered Clay/Epoxy Nano Composites*, Composites Science and Technology 67, 2007, pp3394–3403.